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**SCHOTTKY WITH THICK TRENCH BOTTOM AND  
TERMINATION OXIDE AND PROCESS FOR MANUFACTURE**

**BACKGROUND OF THE INVENTION**

**[0001]** Trench schottky diodes are known. Fig. 1 shows the cross-section of a portion of a trench schottky which is described in the copending U.S. patent Application No. 10/193,783 assigned to the assignee of the present application.

**[0002]** The trench schottky diode shown in Fig. 1 is formed in an epitaxial silicon layer 10 of one conductivity which is formed over a silicon substrate 12 of the same conductivity. Epitaxial layer 10 includes a lower concentration of dopants than substrate 12. Typically, the epitaxial layer 10 and substrate 12 are doped with N-type dopants.

**[0003]** The trench schottky diode shown in Fig. 1 includes a plurality of spaced trenches 14 which extend from the top surface of epitaxial layer 10 to a predetermined depth. Each trench 14 is lined with an oxide layer 16 at its bottom and sidewalls of a substantially uniform thickness of typically about 500 Å to 750 Å, and includes in its interior an electrode 18 formed of a conductive material such as doped polysilicon.

**[0004]** As seen in Fig. 1, between each pair of trenches 14 a mesa 20 is formed. A schottky barrier layer 22 is formed such that it is in schottky contact with mesas 20 and electrical contact with electrodes 18 inside trenches 14. Schottky barrier layer 22 may be formed from, for example, titanium or titanium tungsten. An anode contact 24 which is preferably formed from aluminum is formed over schottky barrier layer 22. The trench schottky diode shown by Fig. 1 also includes cathode contact 26

formed over substrate 12. Cathode contact 26 may be a solderable contact structure such as a trimetal structure.

[0005] The trench schottky diode shown by Fig. 1 also includes termination trench 28 which surrounds the active region of the device. The sidewalls and the bottom of termination trench 28 are also lined with an oxide layer 16. Anode contact 24 extends over the inner sidewall of termination trench 28 and to a portion of the bottom thereof. Also formed at the inner and outer sidewalls of termination trench 28 are conductive polysilicon walls 30. Anode contact 24 may be capacitively connected with epitaxial layer 10 adjacent the inner sidewall of termination trench 28 through polysilicon wall 30. The outer boundary of the trench schottky diode is shown by scribe line 32. Fig. 1 also shows typical dimensional values for the prior art trench schottky diode.

[0006] In a device shown by Fig. 1, when oxide layer 16 is kept at or near 500 Å the device exhibits desirable reverse voltage blocking characteristics for a voltage rating of 15 to 20V. However, thin oxide layers are more prone to oxide breakdown under high reverse voltage conditions and to mechanical fracture of points of high stress, like at the edge of metal field plate. To remedy the problem oxide layer 16 can be thickened to up to about 1200 Å. A trench schottky diode with a thicker oxide layer 16, however, exhibits a higher leakage current, which is undesirable.

#### SUMMARY OF THE INVENTION

[0007] A trench schottky diode according to the present invention includes an oxide layer at the bottom surface of its trenches and relatively thinner oxide layers at the sidewalls of its trenches. The thin oxide layers at the sidewalls of the trenches enable the device to exhibit desirable reverse leakage characteristics, while the thick oxide at the bottom of the trenches improves the ability of the oxide to withstand

breakdown under high reverse voltage conditions, and the ruggedness of the field oxide in high stress points.

[0008] In the preferred embodiment of the present invention the oxide on the sidewalls of the trenches is 500-750 Å thick, while the oxide at the bottom of the trenches is between 1000-5000 Å thick.

[0009] According to another aspect of the present invention, the device according to the present invention includes a termination trench which extends around the trenches in the active area of the device and include a thin oxide layer on a sidewall thereof closest to the active region and a thick oxide layer that extends at least partially along its bottom wall.

[0010] According to another aspect of the present invention, the thick oxide at the bottom of the trenches is grown while the sidewalls of the trenches are covered by an oxidation preventing layer such as a layer of nitride.

[0011] According to another aspect of the present invention, the oxidation preventing layer on the sidewalls of the trenches is formed by first depositing a layer of oxidation preventing material over the sidewalls and the bottoms of the trenches and then dry etching the oxidation preventing material from the bottom of the trenches prior to growing a thick layer of oxide at the bottom of the trenches.

[0012] Other features and advantages of the present invention will become apparent from the following description of the invention which refers to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE FIGURES

[0013] Fig. 1 shows a cross-section of a trench schottky diode according to the prior art.

[0014] Fig. 2A shows a top plan view of a trench schottky diode according to the present invention.

[0015] Fig. 2B shows a cross-sectional view of a trench schottky diode according to the present invention along line 2B-2B in Fig. 2A, viewed in the direction of the arrows.

[0016] Figs. 3A-3H illustrate a method for manufacturing a trench schottky device according to the present invention.

#### DETAILED DESCRIPTION OF THE FIGURES

[0017] Referring to Fig. 2A and Fig. 2B, a trench schottky diode according to the present invention includes all of the features of a prior art trench schottky diode (see Fig. 1) except that, unlike the prior art trench schottky diode of Fig. 1, a trench schottky diode according to the present invention includes thick oxide layer 34 formed on the bottom surface of trenches 14 and termination trench 28. Thick oxide layer 34 may be 1000-5000 Å thick.

[0018] Referring now to Figs. 3A-3H, a process for manufacturing a trench schottky diode according to the present invention will be described.

[0019] Referring first to Fig. 3A, a preferably 600 Å-800 Å thick layer of Silicon Nitride 36 is formed over epitaxial silicon layer 10. Epitaxial silicon layer 10 is formed over silicon substrate 12 which includes dopants of the same conductivity as the dopants in epitaxial silicon layer 10, but of higher concentration. In the preferred embodiment of the present invention, epitaxial silicon layer 10 and substrate 12 are doped with N-type dopants.

[0020] Next, through a photolithographic step windows 38, 40 are defined in the layer of silicon nitride 36, and trenches 14 and termination trench 28 are formed by anisotropically etching epitaxial layer 10 below windows 38, 40 to form trenches 14 and termination trench 28 respectively as shown by Fig. 3B.

[0021] Referring next to Fig. 3C, a preferably 1000-1300 Å thick layer of sacrificial oxide 16 is formed over the sidewalls and bottom of trenches 14 and

termination trench 28. Next, the sacrificial oxide is removed by wet etch. Then the gate oxide is grown to a thickness of 500-750Å over the sidewalls and bottom of trenches 14 and termination trench 28. Thus, silicon nitride 36 having openings therein acts as both a mask for forming trenches 14 and termination trench 28, and for forming oxide 16 over the sidewalls of trenches 14 and termination trench 28. Preferably, oxide 16 layer is grown through oxidation of sidewalls of trenches 14 in a well known oxidation step.

**[0022]** Thereafter, as shown by Fig. 3D, a preferably 150-200Å thick layer of nitride 42 is deposited over the structure shown by Fig. 3C, and through dry nitride etching nitride 42 is removed from the bottom of trenches 14 and termination trench 28 leaving nitride 42 walls on the sidewalls of trenches 14 and termination trench 28 as shown by Fig. 3E.

**[0023]** A preferably 1000-5000 Å thick oxide layer 34 is then formed at the bottom of trenches 14 and termination trench 28 as shown by Fig. 3F, and then walls of nitride 42 on the sidewalls of termination trench 28 and trench 14, and portions of silicon nitride 36 from the top surface of epitaxial layer 10 are removed by a wet etch. The target wet etch at this step is preferably between 200-250 Å. Preferably, thick oxide layer 34 is formed by low temperature oxidation in a well known oxidation step.

**[0024]** Next, as shown by Fig. 3G, a layer of polysilicon 44 is deposited over the structure shown by Fig. 3F. Boron atoms are then implanted into the layer of polysilicon 44 and driven in a thermal step. Subsequently, the layer of polysilicon 44 is anisotropically etched leaving electrodes 18 in trenches 14 and polysilicon on the inner and outer sidewalls of termination trench 28. The remaining portions of nitride 36 is then removed by wet nitride etching to obtain the structure shown by Fig. 3H.

**[0025]** Next, the top surface of epitaxial layer 10 is cleaned by a suitable pre-metal cleaning step not containing HF. A layer of a schottky barrier metal, such as

titanium, or titanium-tungsten (TiW), etc. is next formed on the top surface of epitaxial layer 10 at a thickness of approximately 600 Å. Any technique can be used for formation of the layer of schottky barrier; sputtering and electron beam evaporation are the most common techniques.

**[0026]** If titanium is used, preferably, a 600Å layer of titanium is sputtered and annealed at a high temperature in an inert atmosphere. As a consequence, the thin titanium layer reacts with the epitaxial silicon 10 to form a titanium silicide layer over the active region, thereby forming schottky barrier 22 over the top of mesas 20. The non-reacted titanium layer extending along the termination trench 28 may then be removed by etching with any known Ammonium Hydroxide and Hydrogen Peroxide-based solution. Etch time can vary, but etch temperature should not exceed 80°C to avoid excessively fast decomposition of the H<sub>2</sub>O<sub>2</sub>.

**[0027]** Anode contact 24, which may be a layer of aluminum or other conductive metal layer is next deposited. A metal mask (not shown) is applied for further etching to remove partly a peripheral portion of the anode contact within the termination trench 28 leaving a portion of the bottom of termination trench 28 covered by anode contact 24. Trimetal Ti/Ni/Ag is then sputtered on substrate 12 to form cathode contact 26, thus obtaining a trench schottky diode as shown by Figs. 2A and 2B. One skilled in the art would recognize that a plurality of trench schottky diodes according to the present invention may be formed in a wafer and then singulated by dicing along scribe line 32 to obtain individual trench schottky diodes according to the present invention.

**[0028]** Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the specific disclosure herein, but only by the appended claims.